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Inhibitory Effects of Fungicides on Hydrolysis of Urea and Nitrification of Urea Nitrogen in Soil

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Abstract: The influence of 1 and 50 mg active ingredient (AI) kg^{-1} soil of 17 fungicides on transformations of urea nitrogen in soil was studied by determining the amounts of urea hydrolysed and the amounts of nitrate and nitrite produced when samples of two coarse-textured and two fine-textured soils were incubated aerobically for various times after treatment with urea. When applied at the rate of 1 mg AI kg^{-1} soil, anilazine, benomyl, captan, chloranil, mancozeb and thiram retarded urea hydrolysis in the two coarse-textured soils and maneb retarded urea hydrolysis in all four of the soils used. Most of the fungicides tested retarded nitrification of urea nitrogen in the two coarse-textured soils when applied at the rate of 1 mg AI kg^{-1} soil, but only etridiazole markedly retarded nitrification of urea nitrogen in all of the soils used when applied at this rate. When the fungicides were applied at the rate of 50 mg AI kg^{-1} soil, anilazine, captan, chloranil, fenaminosulf, folpet, maneb, mancozeb and thiram retarded urea hydrolysis in the four soils studied, and all fungicides tested except chloroneb, fenarimol and iprodione retarded nitrification of urea nitrogen in these soils. One-way analysis of variance and correlation analyses indicated that the inhibitory effects of the 17 fungicides tested on nitrification of urea nitrogen in soil increased with decrease in the organic-matter content and increase in the sand content of the soil.

Key words: fungicides, urea transformations, nitrification, soil

1 INTRODUCTION

Urea is now the most important nitrogenous fertilizer in world agriculture,[1] and the popular trend towards application of pesticides in combination with urea-based fertilizer solutions[2] has emphasized the need for information concerning the effects of pesticides on transformations of urea nitrogen in soils. Although fungicides are used less extensively than herbicides or insecticides, the intensive and repeated use of fungicides in conjunction with urea fertilizers on turfgrass and on rice and other crops has created concern about their possible adverse effects on non-target organisms affecting soil microbiological processes.[3,4] Most of the problems associated with urea fertilizer use arise largely from the normally rapid hydrolysis of urea by soil urease ($NH_2CONH_2 + H_2O \rightarrow 2NH_3 + CO_2$) and a resulting rise in pH and accumulation of NH_4^+.[5] They include damage to seeds, seedlings and young plants, ammonia and/or nitrite toxicity and volatilization of urea nitrogen as ammonia.

Nitrification is one of the most pesticide-sensitive microbiological transformations.[6,7] Numerous studies of the effects of pesticides on nitrification of NH_4^+ have been reported,[8] but little is known about the effects of fungicides on nitrification of urea nitrogen in soil. In general, the effect of a particular pesticide on nitrification has been shown to vary with the amount applied and with soil properties and environmental factors.[9]

Several technical-grade fungicides have been evaluated for their possible effects on nitrification of NH_4^+ in soil. Maneb and anilazine have been reported to inhibit the oxidation of NH_4^+, applied as $(NH_4)_2SO_4$, to nitrate at application rates as low as 15 mg maneb kg^{-1} soil

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TABLE 1
Analyses of Soils

Soil										
Series	*Subgroup*	*pH*	*Organic C*	*Total N*	*Sand*	*Silt*	*Clay*	*CCE*[a]	*CEC*[b]	*Urease activity*[c]
						$(g\ kg^{-1}$ *soil*)				
Buckney	Entic Hapludoll	8·1	4	0·5	800	120	80	300	4	27
Dickinson	Typic Hapludoll	6·0	12	1·3	740	180	80	0	9	12
Webster	Typic Haplaquoll	7·3	33	2·3	330	340	330	10	20	34
Harps	Typic Calciaquoll	7·7	42	4·7	140	440	420	230	29	51

[a] $CaCO_3$ equivalent.
[b] Cation-exchange capacity [cmol $(NH_4^+)\ kg^{-1}$ soil].
[c] Determined by the nonbuffer method of Zantua and Bremner.[15] Expressed as mg urea hydrolysed $h^{-1}\ kg^{-1}$ soil (37°C).

and 60 mg anilazine kg^{-1} soil.[3,10] Captan[11,12] and thiram[12] were found to retard nitrification of NH_4^+ when applied at rates of 250 mg and 100 mg kg^{-1} soil, respectively, but benomyl applied at the rate of 150 mg kg^{-1} soil and quintozene (PCNB) applied at the rate of 1000 mg kg^{-1} soil were found to have no effect on nitrification of NH_4^+.[13]

The need for increased understanding of the influence of pesticide applications on the nitrogen cycle was emphasized by a study by Dubey[14] showing that repeated applications of maneb and other fungicides to a soil used to grow tomatoes in Puerto Rico caused a marked reduction in the soil's bacterial population and resulted in inhibition of both mineralization of organic nitrogen and nitrification of ammonium in this soil.

We report here the results of studies to determine the influence of different amounts of 17 extensively used fungicides on transformations of urea nitrogen in a range of soils. The fungicides studied were anilazine, benomyl, captan, chloranil, chloroneb, chlorothalonil, fenaminosulf, fenarimol, folpet, iprodione, mancozeb, maneb, metalaxyl, metam-sodium, quintozene, etridia-

TABLE 2
Fungicides Studied

Common name	*Chemical name*	*Formulation*[a] (*AI content*)	*Source*[b]
Anilazine	4,6-Dichloro-*N*-(2-chlorophenyl)-1,3,5-triazin-2-amine	WP(500)	M
Benomyl	Methyl 1-(butylcarbamoyl)benzimidazol-2-yl carbamate	WP(500)	P
Captan	*N*-(trichloromethylthio)cyclohex-4-ene-1,2-dicarboximide	WP(500)	S
Chloranil	2,3,5,6-Tetrachloro-2,5-cyclohexadiene-1,4-dione	WP(500)	A
Chloroneb	1,4-Dichloro-2,5-dimethoxybenzene	WP(650)	P
Chlorothalonil	2,4,5,6-Tetrachloro-1,3-benzenedicarbonitrile	EC(500)	D
Etridiazole	Ethyl 3-trichloromethyl-1,2,4-thiadiazol-5-yl ether	L(95)	O
Fenaminosulf	Sodium 4-dimethylaminophenyldiazosulfonate	WP(500)	M
Fenarimol	(±)-2,4′-dichloro-α-(pyrimidin-5-yl)benzhydryl alcohol	EC(144)	E
Folpet	*N*-(Trichloromethylthio)phthalimide	WP(350)	C
Iprodione	3-(3,5-Dichlorophenyl-*N*-isopropyl-2,4-dioxoimidazolidine-1-carboxamide	WP(500)	R
Maneb	Manganese ethylene bis(dithiocarbamate)	WP(800)	P
Mancozeb	Coordination product of zinc ion and maneb	WP(800)	H
Metalaxyl	Methyl *N*-(2-methoxyacetyl)-*N*-(2,6-xylyl)-DL-alaninate	EC(240)	G
Metam-sodium	Sodium methyldithiocarbamate	WP(980)	S
Quintozene	Pentachloronitrobenzene	WP(750)	O
Thiram	Tetramethylthiuram disulfide	WP(650)	P

[a] WP, wettable powder; EC, emulsifiable concentrate; L, Liquid. Values in parentheses indicate g AI kg^{-1} (WP), g AI $litre^{-1}$ (EC) or % purity (L).
[b] M, Mobay Chemical Corp., Kansas City, MO; P, E. I. Dupont de Nemours & Co., Inc., Wilmington, DE; S, Stauffer Chemical Co., Westport, CT; A, Agway Inc., Syracuse, NY; D, Diamond-Shamrock, Cleveland, OH; E, Elanco Products Co., Indianapolis, IN; C, Chevron Chemical Co., San Francisco, CA; R, Rhône-Poulenc, Monmouth, NJ; H, Rohm and Haas Co., Philadelphia, PA; G, Ciba Geigy, Greensboro, NC; O, Olin Corp., Little Rock, AR.

TABLE 3
Effects of 50 mg AI kg^{-1} Soil of Non-sulfur Fungicides on Hydrolysis of Urea Added to Soil (20°C)

Fungicide	*Time (days)*	*Soil* Buckney	Dickinson	Webster	Harps
		inhibition of urea hydrolysis[a] (%)			
Anilazine	1	20 (4)	37 (5)	7	13
	3	18	0	0	0
	7	0	0	0	0
Benomyl	1	24 (3)	43 (6)	10	0
	3	15	4	0	0
	7	0	0	0	0
Chloranil	1	46 (8)	54 (2)	22	19
	3	42	51	14	6
	7	15	49	0	0
Chloroneb	1	0	0	0	0
	3	0	0	0	0
	7	0	0	0	0
Chlorothalonil	1	0	0	0	0
	3	0	0	0	0
	7	0	0	0	0
Fenarimol	1	0	0	0	0
	3	0	0	0	0
	7	0	0	0	0
Iprodione	1	0	0	0	0
	3	0	0	0	0
	7	0	0	0	0
Metalaxyl	1	0	27	0	0
	3	0	0	0	0
	7	0	0	0	0
Quintozene	1	0	0	0	0
	3	0	0	0	0
	7	0	0	0	0

[a] Value in parentheses indicates percentage inhibition of urea hydrolysis when fungicide was applied at the rate of 1 mg AI kg^{-1} soil.

zole and thiram. These turfgrass and crop protection fungicides are commonly used for control of a wide spectrum of fungal-induced plant diseases.

2 MATERIALS AND METHODS

2.1 Soils and fungicides used

The soils used (Table 1) were surface (0–15 cm) samples of Iowa soils selected to obtain a range in pH (6·0–8·1), texture (140–800 g sand, 80–420 g clay kg^{-1} soil) and organic-matter content (4–42 g organic C kg^{-1} soil). Before use, each sample was sieved in a field-moist condition to pass through a 2-mm screen. In the analyses reported in Table 1, pH, calcium carbonate equivalent, organic carbon, urease activity, and texture were determined as described by Zantua and Bremner.[15] Total nitrogen was determined by a semimicro-Kjeldahl procedure[16] and cation-exchange capacity was determined as described by Keeney and Bremner.[17] The names, formulations and sources of the 17 formulated fungicides studied are reported in Table 2. Other chemicals used were obtained from Fisher Scientific Co., Itasca, Illinois.

2.2 Urea hydrolysis

The procedure used to determine the effects of the formulated fungicides on hydrolysis of urea in soil was as follows. Samples of field-moist soil containing 5 g (oven-dry basis) were placed in 65-ml glass bottles and treated with 2 ml of water containing 10 mg of urea or with 2 ml of water containing 10 mg of urea and 0·005 or 0·250 mg active ingredient (AI) of the fungicide under

TABLE 4
Effects of 50 mg AI kg^{-1} Soil of Sulfur Fungicides on Hydrolysis of Urea Added to Soil (20°C)

Fungicide	*Time (days)*	*Soil*			
		Buckney	*Dickinson*	*Webster*	*Harps*
		inhibition of urea hydrolysis[a] (%)			
Captan	1	52 (12)	48 (10)	17	33
	3	49	44	15	3
	7	12	35	0	0
Etridiazole	1	0	0	0	0
	3	0	0	0	0
	7	0	0	0	0
Fenaminosulf	1	21	8	12	7
	3	12	7	2	0
	7	0	0	0	0
Folpet	1	48	43	20	16
	3	15	41	8	1
	7	0	20	0	0
Maneb	1	78 (25)	58 (12)	39 (9)	48 (8)
	3	59	56	37	17
	7	40	45	3	0
Mancozeb	1	60 (16)	56 (10)	42 (13)	36
	3	48	54	40	24
	7	36	49	5	0
Metam-sodium	1	11	25	6	0
	3	10	17	0	0
	7	0	0	0	0
Thiram	1	65 (25)	55 (10)	33 (5)	35
	3	28	51	26	3
	7	25	46	0	0

[a] Value in parentheses indicates percentage inhibition of urea hydrolysis when fungicide was applied at the rate of 1 mg AI kg^{-1} soil.

study. The bottles were then sealed with rubber stoppers covered with aluminum foil and placed in an incubator at 20°C for 1, 3 or 7 days. Urea in the incubated soil samples was extracted with potassium chloride solution (2 M) containing phenylmercuric acetate (urease inhibitor; 5 mg $litre^{-1}$) as described by Douglas and Bremner[18] and determined by the colorimetric method described by Mulvaney and Bremner.[19] Percentage inhibition of urea hydrolysis by the fungicide studied was calculated from $(C_h\text{-}T_h)/C_h \times 100$, where T_h = amount of urea hydrolysed in the soil sample treated with fungicide and C_h = amount of urea hydrolysed in the control (no fungicide added).

2.3 Nitrification of urea

The procedure used to determine the effects of the formulated fungicides on nitrification of urea nitrogen in soil was as follows. Samples of field-moist soil containing 10 g (oven-dry basis) were placed in 250-ml French square bottles and treated with 2 ml of water containing 10 mg of urea or with 2 ml of water containing 10 mg of urea and 0·010 or 0·500 mg AI of the fungicide under study. The bottles were then sealed with rubber stoppers covered with aluminium foil and placed in an incubator at 20°C for 7, 14 or 21 days. The bottles were aerated at three-day intervals during incubation. The incubated soil samples were analyzed for NH_4^+ nitrogen and NO_3^- nitrogen by the steam-distillation methods described by Bremner and Keeney[20] and for NO_2^- nitrogen by the colorimetric procedure described by Bremner.[21] The amount of NO_2^- nitrogen produced during incubation was calculated from the results of analyses for $(NO_2^- + NO_3^-)$ nitrogen before and after incubation, and percentage inhibition of nitrification by the fungicide studied was calculated from $(C_n\text{-}T_n)/C_n \times 100$, where T_n = amount of $(NO_2^- + NO_3^-)$ nitrogen produced in the soil sample treated with fungicide and C_n = amount of $(NO_2^- + NO_3^-)$ nitrogen produced in the control (no fungicide added).

All analyses and experiments reported were performed in duplicate or triplicate. Analysis of variance

TABLE 5
Effects of 50 mg AI kg^{-1} Soil of Non-sulfur Fungicides on Nitrification of Urea Nitrogen in Soil (20°C)

Fungicide	Time (days)	Soil: Buckney	Dickinson	Webster	Harps
		inhibition of nitrification[a] (%)			
Anilazine	7	65 (30)	50 (18)	5	0
	14	20 (16)	38 (16)	0	0
	21	0	20	0	0
Benomyl	7	20	38	2	0
	14	16	25	0	0
	21	0	18	0	0
Chloranil	7	70 (60)	80 (57)	9	16
	14	10 (5)	65	2	4
	21	5	50	0	0
Chloroneb	7	0	0	0	0
	14	0	0	0	0
	21	0	0	0	0
Chlorothalonil	7	90	70	15	10
	14	35	20	7	0
	21	0	0	0	0
Fenarimol	7	0	0	0	0
	14	0	0	0	0
	21	0	0	0	0
Iprodione	7	0	0	0	0
	14	0	0	0	0
	21	0	0	0	0
Metalaxyl	7	90 (60)	90 (29)	22	99
	14	93	90	8	99
	21	93	90	3	93
Quintozene	7	50 (30)	63	8	0
	14	26	20	0	0
	21	0	10	0	0

[a] Value in parentheses indicates percentage inhibition of nitrification when fungicide was applied at the rate of 1 mg AI kg^{-1} soil.

and correlation analyses were performed in accordance with SAS procedures.[22]

3 RESULTS AND DISCUSSION

The fungicide rates chosen for this work reflect the recommended application rate (1 mg AI kg^{-1} soil) and a rate possible as a result of a build-up of fungicide concentration in soil due to weekly fungicide applications as in a golf green situation or other intensively managed agricultural operation (50 mg AI kg^{-1} soil).

To simplify presentation of the results, the 17 fungicides studied are classified here as sulfur-containing or non-sulfur-containing fungicides. When the nine non-sulfur fungicides tested were applied at the rate of 1 mg AI kg^{-1} soil, none of them retarded urea hydrolysis in the two fine-textured soils (Webster and Harps), but anilazine, benomyl and chloranil retarded urea hydrolysis in the two coarse-textured soils (Buckney and Dickinson) (Table 3). When the non-sulfur fungicides were applied at the rate of 50 mg AI kg^{-1} soil, anilazine, benomyl and chloranil retarded urea hydrolysis in the two coarse-textured soils, but only anilazine and chloranil retarded hydrolysis of urea in all four of the soils used (Table 3). Bundy and Bremner[23] found that chloranil and other substituted quinones were potent inhibitors of soil urease when applied at the rate of 50 mg kg^{-1} soil.

When the eight sulfur fungicides were applied at the rate of 1 mg AI kg^{-1} soil, captan, mancozeb and thiram retarded urea hydrolysis for 24 h in the two coarse-textured soils and maneb retarded urea hydrolysis for 24 h in all of the soils used (Table 4). When the same fungicides were applied at the rate of 50 mg AI kg^{-1} soil, most of them retarded urea hydrolysis in the four soils used for at least 24 h (Table 4), and captan, maneb, mancozeb and thiram retarded urea hydrolysis in the

TABLE 6
Effects of 1 mg AI kg^{-1} Soil of Sulfur Fungicides on Nitrification of Urea Nitrogen in Soil (20°C)

Fungicide	*Time (days)*	*Soil* Buckney	Dickinson	Webster	Harps
		inhibition of nitrification (%)			
Captan	7	43	29	0	0
	14	40	0	0	0
	21	6	0	0	0
Etridiazole	7	100	93	73	76
	14	100	93	64	64
	21	99	94	20	13
Fenaminosulf	7	60	57	0	0
	14	57	0	0	0
	21	5	0	0	0
Folpet	7	67	57	0	0
	14	40	5	0	0
	21	0	0	0	0
Maneb	7	40	44	20	0
	14	31	29	0	0
	21	0	20	0	0
Mancozeb	7	40	43	0	0
	14	35	29	0	0
	21	0	10	0	0
Metam-sodium	7	50	30	0	0
	14	31	5	0	0
	21	0	0	0	0
Thiram	7	83	20	0	0
	14	60	0	0	0
	21	7	0	0	0

coarse-textured soils for up to one week. The extensive retardation of urea hydrolysis by application of the sulfur fungicides may promote leaching of urea during irrigation. Etridiazole was the only sulfur fungicide tested that did not retard urea hydrolysis when applied at the two rates tested.

Table 5 shows the effects of 1 and 50 mg AI kg^{-1} soil of the nine non-sulfur fungicides studied on the nitrification of urea nitrogen in the four soils used. None of these fungicides retarded nitrification of urea nitrogen in the fine-textured soils when applied at the rate of 1 mg AI kg^{-1} soil, but anilazine, chloranil and metalaxyl retarded nitrification of urea nitrogen in the both coarse-textured soils when applied at this rate. All of the non-sulfur fungicides except chloroneb, fenarimol and iprodione retarded nitrification in the two coarse-textured soils when applied at the rate of 50 mg AI kg^{-1} soil, and chloranil, chlorothalonil and metalaxyl retarded nitrification of urea nitrogen in the four soils when applied at this rate (Table 5). The prolonged (>21 days) inhibition of nitrification observed with metalaxyl application indicates that use of this fungicide for pathogen control may affect the utilization of nitrogen by plants.

The effects of 1 and 50 mg AI kg^{-1} soil of the eight sulfur fungicides tested on the nitrification of urea nitrogen in soil are shown in Tables 6 and 7, respectively. When applied at the rate of 1 mg AI kg^{-1} soil, all of the sulfur fungicides tested retarded the nitrification of urea nitrogen in the two coarse-textured soils and etridiazole effectively retarded nitrification of urea nitrogen in all four of the soils used (Table 6). When applied at the rate of 50 mg AI kg^{-1} soil, the eight sulfur fungicides retarded the nitrification of urea nitrogen for up to 21 days in all four of the soils used (Table 7). Etridiazole is the active ingredient in 'Dwell', a soil nitrification inhibitor patented by Olin Corporation (Little Rock, AR). Maneb, mancozeb, metam-sodium and thiram were as effective as etridiazole in retarding the nitrification of urea nitrogen in the four soils used when they were applied at the rate of 50 mg AI kg^{-1} soil, but etridiazole was the most effective inhibitor of nitrification of urea nitrogen when the sulfur fungicides were applied at the rate of 1 mg AI kg^{-1} soil.

The extensive retardation of nitrification of urea nitrogen in the soils tested by most of the fungicides studied suggests that the nitrogen status of a soil will be disturbed by application of these fungicides because

TABLE 7
Effects of 50 mg AI kg^{-1} Soil of Sulfur Fungicides on Nitrification of Urea Nitrogen in Soil (20°C)

Fungicide	*Time (days)*	*Soil*			
		Bucknev	*Dickinson*	*Webster*	*Harps*
		inhibition of nitrification (%)			
Captan	7	90	90	84	80
	14	88	90	32	54
	21	87	90	19	9
Etridiazole	7	100	100	96	100
	14	100	100	96	100
	21	100	100	95	100
Fenaminosulf	7	90	63	53	71
	14	87	60	15	45
	21	37	60	13	19
Folpet	7	90	90	73	88
	14	70	75	26	53
	21	55	72	3	11
Maneb	7	100	95	96	100
	14	100	95	91	100
	21	100	94	90	98
Mancozeb	7	100	90	98	100
	14	100	90	96	100
	21	100	90	93	98
Metam-sodium	7	100	95	84	100
	14	100	90	76	97
	21	100	90	51	58
Thiram	7	100	95	77	100
	14	100	90	64	100
	21	100	90	57	93

there is evidence that long-term inhibition of nitrification can have an adverse effect on plant growth. For example, Feng and Barker[24] found that corn and soybean growth was restricted when nitrogen was maintained as NH_4^+ rather than nitrate by addition of captan or etridiazole. Phytotoxic symptoms of plants associated with inhibition of nitrification have been found to vary greatly with the concentration of inhibitor applied, and with plant species and soil characteristics.[25–28] Some of these symptoms are typical of ammonium toxicity (e.g. retarded growth, inter-veinal chlorosis, marginal chlorosis and growth aberrations).

Nitrification has been defined by the Soil Science Society of America[29] as the 'biological oxidation of NH_4^+ to nitrite and nitrate'. The data presented in Table 8 show that treating the coarse-textured Buckney soil with certain fungicides resulted in a large accumulation of urea nitrogen as nitrite. This inhibition of the activity of the *Nitrobacter* sp. responsible for oxidation of nitrite in soil was pronounced in the Buckney soil even when certain fungicides were applied at the rate of 1 mg AI kg^{-1} soil. This suggests that application of these fungicides with urea fertilizers to coarse-textured soils may lead to plant damage *via* nitrite toxicity. In addition, an increased nitrogen deficit was detected in the fungicide-treated soil compared to the non-fungicide-treated soil when the fungicides tested inhibited conversion of NH_4^+ to nitrate (Table 8). The nitrogen deficits found in our work were due to the loss of urea nitrogen as ammonia (data not shown). This finding was in agreement with conclusions reported by Bundy and Bremner[30] that treatment of certain soils with nitrification inhibitors led to an increased loss of urea nitrogen by the volatilization of ammonia from soil treated with urea.

One-way analysis of variance was used to examine the data concerning the effects of 50 mg AI kg^{-1} soil of the 17 fungicides tested on nitrification of urea nitrogen when the four soils studied were incubated at 20°C for 7, 14 or 21 days after treatment with urea (Tables 5 and 7). The results showed that variations among soil type, specific fungicide applied and incubation time had significant ($P \leqq 0{\cdot}001\%$) effects on the nitrification of urea nitrogen, but that the F value was much greater for soil type. Simple correlation analyses showed that the percentage inhibition of nitrification of urea nitrogen by the fungicides tested was significantly correlated with organic carbon content ($r = -0{\cdot}83^{**}$), total nitrogen content ($r = -0{\cdot}61^{*}$), sand, silt and clay contents ($r = 0{\cdot}82^{**}$, $-0{\cdot}79^{**}$ and $-0{\cdot}84^{**}$, respectively), urease activity ($r = -0{\cdot}61^{*}$) and cation-exchange capacity

TABLE 8
Effects of 1 and 50 mg AI kg^{-1} Soil of Fungicides on Recovery of Urea Nitrogen in Different Forms after Incubation of Buckney Soil with Urea at 20°C for 21 Days

Fungicide	*Amount added (mg AI kg^{-1} soil)*	*Recovery of urea N (%) as*				
		Urea	NH_4^+	NO_2^-	NO_3^-	*Total*
None		0	6	31	54	91
Non-sulfur fungicides						
Anilazine	1	0	6	32	54	92
	50	0	5	75	10	90
Benomyl	1	0	4	52	34	90
	50	0	5	73	15	93
Metalaxyl	1	0	6	74	11	91
	50	0	75	3	3	81
Quintozene	1	0	6	77	7	90
	50	0	7	78	6	91
Sulfur fungicides						
Captan	1	0	4	73	15	92
	50	0	71	5	6	82
Maneb	1	0	4	74	14	92
	50	0	82	0	0	82
Mancozeb	1	0	2	80	7	89
	50	0	83	0	0	83
Thiram	1	0	15	61	14	90
	50	20	62	0	0	82

($r = -0{\cdot}76^*$), but was not significantly correlated with pH or calcium carbonate equivalent. These simple correlations indicate that organic matter content and soil texture are important soil factors regulating the inhibition of nitrification of urea nitrogen by the fungicides studied.

4 CONCLUSIONS

Application of sulfur-containing fungicides at the two rates tested had a greater inhibitory effect on urease activity and nitrification of urea nitrogen in the soils studied than did application of the non-sulfur fungicides. Chloroneb, fenarimol and iprodione were the only fungicides tested that did not retard urease activity or nitrification of urea nitrogen. Retardation of nitrification by fungicide addition was greater in the sandy soils with low organic carbon contents than in the fine-textured soils. The retardation of urea hydrolysis and the concomitant decrease in the nitrification rate of urea nitrogen by a single application of several sulfur fungicides tested suggest that multiple applications of these fungicides with urea fertilizers will affect the availability of soil nitrogen to plants.

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